

## ***Interactive comment on “HESS Opinions “Hydrologists, bring out shovels and garden hoses and hit the dirt”” by M. G. Kleinhans et al.***

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We thank the reviewers for their constructive and positive comments. Below we summarise and address each reviewer comment and explain how we modify the paper in response.

Comment 1: Remove sections 2.1 (observation) and 2.2 (modelling) and move directly to 2.3 (experiments) for clarity.

Reply 1: That would take the heart out of the paper. To appreciate the benefits and shortcomings experiments the contrast to those of observation and of modelling is required. The whole idea of the paper is to clarify how geoscientists conceive and

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test hypotheses through a combination of these three approaches, with the secondary objective to supply the community with concepts for discourse on geoscientific methodology. The three referees all agree that hydrology could use more controlled experimentation, and the paper aims to clarify how and why. Furthermore there is a useful style of modelling that simplifies boundary and initial conditions in a similar way as experiments do, which we believe leads to better understanding.

Comment 2: Outline concrete examples where experiments had a transformative effect on related subfields, and exhaustively list experimental efforts in hydrology.

Reply 2: We thank reviewer 3 for supplying these references. We have moved section 2.3.2 on experiments in hydrology to chapter 3 on experiments in general and extended somewhat using the suggested references. Given the request to reduce paper length, however, we cannot provide an exhaustive list. Neither do we want to do this; examples should suffice to drive the message home that controlled experiments are beneficial to our understanding.

Comment 3: Change the title.

Reply 3: We changed it to include On the use of laboratory experimentation as this covers how we use laboratory experimentation in explanation and understanding.

Comment 4: Perhaps speculate on why there has not been more experimental work in hydrology.

Reply 4: This request is related to the question by reviewer 1 about the grand challenges of hydrology and how experimentation can help. We suggest three possible reasons why experimentation is relatively rare in hydrology:

- Historically there is an emphasis on good prediction for direct use by the society. In addition to statistical methods based on observation, modelling is the logical tool for operational prediction, so it is not surprising that there has been a lot of effort in hydrological modelling, particularly highly detailed reductionistic modelling

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and data-model integration.

- There is a mismatch between the time scale of interest and the spatial scale of interest in hydrological prediction in large basins. In general it takes more time to erode an entire mountain range than it takes to carve a minor gully. For the large-scale phenomenon the short-duration changes in forcing are irrelevant whilst an average forcing produces the phenomenon well (see discussion above on channel-forming discharge in rivers). In catchment hydrology short-term changes (floods) are of interest over large spatial scales. Spatial variation in parameters (called initial conditions in other contexts) such as permeability etc. is caused by long-term landscape evolution and are therefore not co-evolved in the model. This means that, contrary to geomorphology, much more must be specified (from observations) for good predictions of the phenomena of interest. In agreement with this suggestion, experiments aimed at understanding entire catchments or aquifers seem to be much more rare than small-scale laboratory experiments on elements of the system or particular pore-scale processes such as wetting phenomena.
- There may be a cultural aspect to the emphasis on observation and modelling in hydrology. The scarcity of experiments in literature and in presentations at conferences does perhaps not stimulate the use of experiments to address the grand challenges of hydrology.

At present and in the near future, there is a growing demand for longer-term predictions in view of global change issues and growing anthropogenic pressure on the environment. For such longer-term predictions the feedbacks between hydrology, vegetation, soil, morphology and so on become more important, so there is a move towards more interdisciplinary approaches. Therefore the focus is also shifting from operational prediction to understanding. For explanatory modelling, of which results cannot directly be compared to data for verification, the question then arises whether particular outcomes

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are model artifacts or real phenomena, which can be tested by creative and controlled experimentation. Furthermore ungauged basins receive more attention, for which the detailed initial and boundary conditions required for detailed reductionistic modelling may not be available. These are not grand challenges of hydrology alone, but of all earth system sciences. To address these grand challenges, controlled laboratory experiments and explanatory modelling will become more important tools.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 6581, 2009.

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